Propulsion Technology Planning for Engine Health Management

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Outline

- Introduction to AFRL/PR's Turbine Engine Technology Plans
- Affordability Metric
- Maintenance Cost Drivers
- VAATE Engine Health Management Vision
  - three levels of capability
- DoD EHM Ground Power Relevancy
- Summary

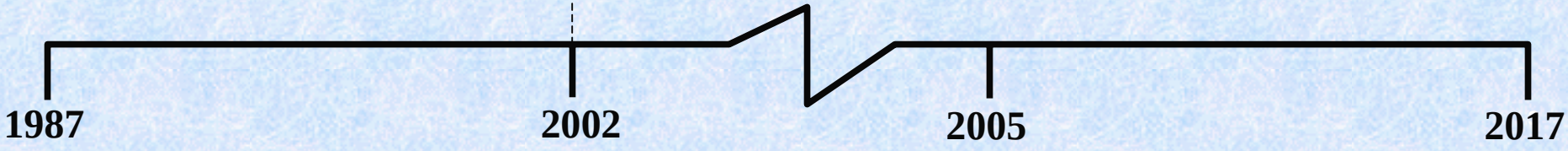
Turbine Engine S&T Plan
Tri-Service/NASA/Industry Coordinated

***Integrated High Performance Turbine Engine Technology (IHPTET)…*Constant Life (F119)**

- 2X Propulsion Capability
  - +100% Engine Thrust/Weight
  - -40% Fuel Burn
  - -35% Production & Maintenance Cost
- National HCF S&T Program

Versatile, Affordable, Advanced Turbine Engines

- 10X Propulsion Affordability (Capability / Cost)
  - National Durability Program
  - Maintenance Friendly Versatile Core
  - Ultra-Intelligent Adaptive Engine
- Environmental Efficiencies
- Dev/Prod/Maint Cost Reduction Focus



VAATE Focus Areas

Intelligent Engine -

High Performing, Damage Tolerant

- **Adaptive Component Performance**
- Integrated Propulsion & Power
- **Real Time Life Tracking**
- **Proactive Health Management**

Durability -

Turbine Engine Readiness Issues

- High Cycle Fatigue (HCF) Protocol
- Other Robust Engine Protocol
- Validated Design Methods Through Testing

Versatile Core -

Military/Civil Multi-Use, Maintenance-Friendly

- Innovative Engine Architecture
- Wide Flow / High Efficiency Components
- Hi Excess Horsepower Technology
- Reduced Combustion Emissions

Revolutionary Features:

- No Lubrication or Hydraulic System
- Fuel Efficient, Variable Cycle
- Reduced Noise & Combustion Emissions
- Self Contained Diagnostics, Boltless Assembly
- Robust: Tolerant to Variations
- Integrated Stealth Technologies

VAATE Goal Metric

- **New affordability metric established for VAATE**

$$\textit{Cost Capability Index (CCI)} = \frac{\text{Propulsion}}{\text{Capability/Cost Index}} = \frac{\text{Capability}}{\text{Cost}} = \frac{\text{(Thrust/Wt)/(SFC)}}{\text{(Cost)}}$$

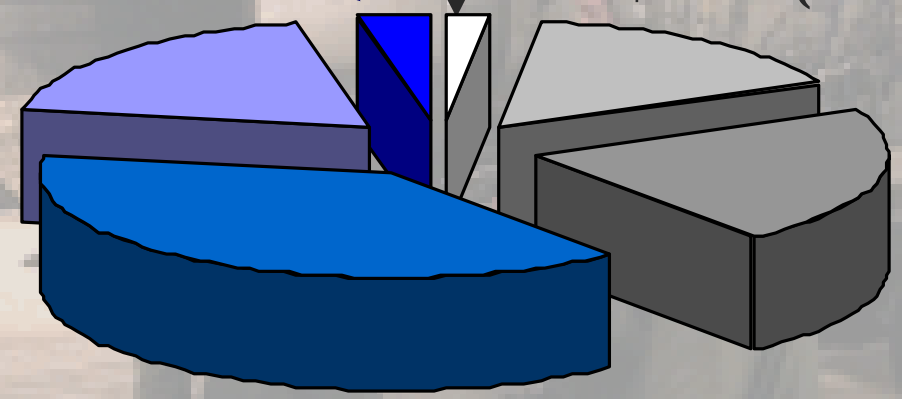
Where:

Cost ~ Σ (Development, Production, & **Maintenance Cost**)

Engine Technology

F119	**Base**
IHPTET	**2X Capability**
VAATE	**10X Affordability**

Propulsion System Affordability



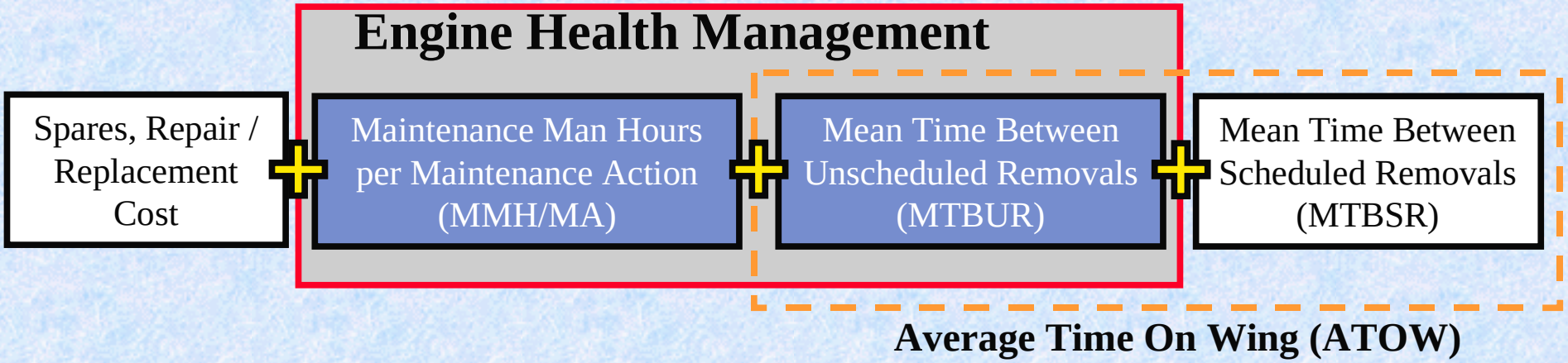
Engine Health Management is targeted towards reducing this $3.3B+ sustainment cost

FY00 Budgets

(Fuel Cost NOT included)

Sustainment Cost Breakdown

Sustainment Cost =



ATOW goal for F100's and F110's averages 450 hrs.
On average, we only achieve an ATOW of 229 hrs*

*Source: CEMS Database

Maintenance Cost Objectives
How EHM is going to help Sustainment Cost

-60% Maintenance Cost $/EFH

Durability:
1) Double component life (MTBSR +100%)
- Design methods/protocol & Failure mechanisms
- Lifing Methods
- Materials characterization
- Validation testing

2) Reduce repair/replace costs (-30%)
- Manufacturing Processes

Intelligent Engine (EHM):
1) Extend MTBUR (+75%)
- Model based diagnostics
- Information gathering & fusion
- Active component control
- Robust sensors/virtual sensors
- Condition based performance

2) Reduce MMH/MA (-50%)
- Improved inspections (on-wing)
- Prognostic health management

Versatile Core:
1) Extend MTBUR (+25%)
- Cooled cooling Air
- Thermal Barrier Coatings
- Advanced Materials
- Magnetic Bearings
- Electronic Actuation

2) Reduce repair/replace costs (-10%)
- Ease-of-assembly
- Parts commonality

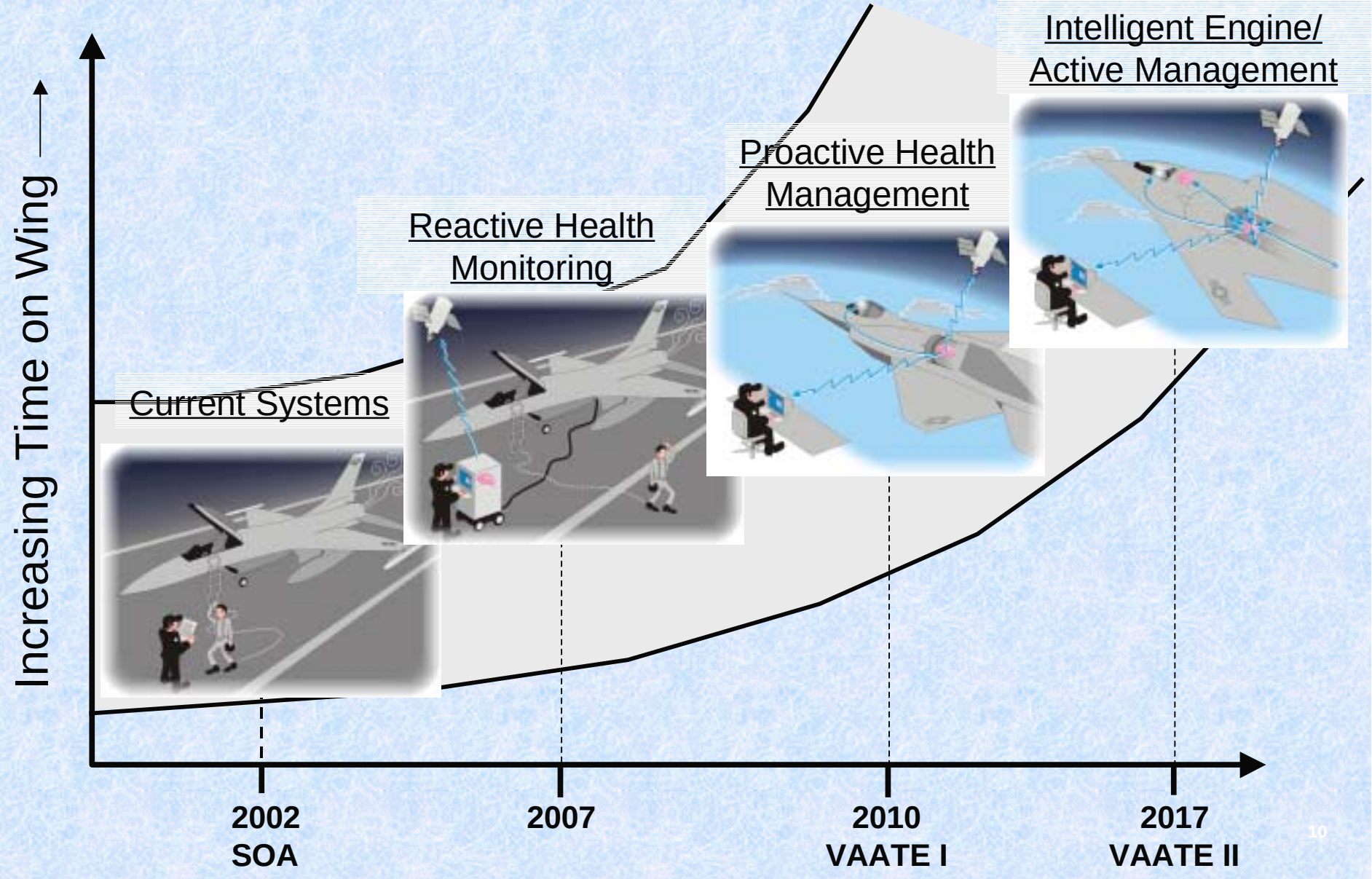
All focus areas contribute to the 60% maintenance cost reduction;

Intelligent Engine provides engine health management

VAATE EHM Mission Statement

Through integrated ground-based and on-board control, diagnostic, and prognostic systems, maximize engine time-on-wing while minimizing support cost without compromising performance and survivability; Provide flexible health management technologies that can be integrated into legacy, pipeline, and future propulsion

EHM Time-Phased Descriptors



VAATE Element Descriptions

Diagnostics

- Real Time Crack Detection
- Advanced Vibration Diagnostics
- Oil Condition Monitoring
- T41 & Emissions Sensors
- Bearing Health Sensor
- Advanced Inspection Capability

Maintenance Process Control

- Data Mining/Data Integration
- Autonomic Logistics & Training
- Comprehensive Data Warehouse
- Every Engine a Website

Prognostics

- Advanced Mission Analysis
- Data Trending and Diagnostics
- Physics Based Component Life Models
- Information Fusion/Knowledge
- Advanced Reasoning

Controls

- Electric Actuation
- Active Component Control
- Model Based & Nonlinear
- Hi Temp Electronics
- Continuous Life Tracking
- Hi Temp Power Conversion

Four EHM Elements

Reduce Maintenance Effort	•**Maintenance Process Control:** Optimizing the Maintenance Process through Information Management. •**Diagnostics:** Determining current health of parts (State Awareness/Life Usage).
Reduce Unscheduled Removals	•**Prognostics:** Predicting when a part will fail (Remaining Life) and how to delay or prevent its failure (Life Extension). •**Active Control:** Closed loop engine feedback to improve performance, extend life, and reduce maintenance actions.

Intelligent Engine S&T Plan

Diagnostics & Process Control

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VAATE Goal

10X Capability/Cost

GOALS Factors

- **Thrust/Weight (3X)**
- **Development Cost (-65%)**
- **Maintenance Cost (-70%)**
- **Production Cost (-60%)**
- **TSFC (-25%)**

OBJECTIVES

ATOW

- Mean Time Between Scheduled Removals (+100%)
- **Mean Time Between Unscheduled Removals (+75%)**

- **Maint. Manhrs per Maint. Action (-50%)**

TECH CHALLENGES

- DURABILTY
- VERSATILE CORE
- Difficult to detect faults & reduce inspection time due to insufficient monitoring
- Difficult to isolate faults due to data interpretation
- Difficult to reduce maintenance time due to complex logistics and training

APPROACHES

- Improved On-Wing Inspections
- Tracking & Failure Detection Sensors

Total Condition Awareness

- Learning Algorithms
- Data Trending
- Data Fusion & Reasoning

- Logistics Information Fusion
- Autonomic Logistics/Training

(Right Support, Right Time Right Reason - R^3)

Intelligent Engine S&T Plan

Prognostics & Active Controls

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VAATE Goal

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OBJECTIVES

ATOW

- Mean Time Between Scheduled Removals (+100%)
- **Mean Time Between Unscheduled Removals (+75%)**

- **Maint. Manhrs per Maint. Action (-50%)**

TECH CHALLENGES

- DURABILTY
- VERSATILE CORE
- Difficult to monitor health and life due to condition uncertainty
- Difficult to prevent operating exceedences due to direct control limitations
- Difficult to proactively manage health on-line due to poor information gathering, Distribution, and interpretation

APPROACHES

- Robust Sensors
- Virtual Sensors
- Imbedded Lifing Models

Condition Based Performance:

- Data trending
- Data Fusion & Reasoning
- Learning Algorithms
- Active Control

- Engine Level Information Fusion
- Model Based Diagnostics

DoD EHM Relevance to Ground Power

Commonality exists in three of four EHM elements:

Diagnostics: Determining current health of parts (State Awareness/Life Usage).

Prognostics: Predicting when a part will fail (Remaining Life) and how to delay or prevent its failure (Life Extension).

Active Control: Closed loop engine feedback to improve performance, extend life, and reduce maintenance actions.

Summary

- Pursuing Engine Health Management (EHM) S&T activities to reduce maintenance costs

- Many EHM areas directly tie to DOE needs

- Several near-term technology transition opportunities available

- We would appreciate any feedback on our proposed plan